FM HD Radio™ System Performance

At

Elevated Carrier Levels

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1 Overview

This report documents recent field tests of iBiquity Digital Corporation's FM HD Radio™ system. The tests were designed to assess the system's performance with an increase in the ratio of digital power to analog power. These tests compare the system performance at current power levels (digital power 20 dB below analog power) with elevated power levels (digital power 10 dB below analog).

1.1 IBOC Signal

For these tests, the system operated in the hybrid mode, which contains the analog FM signal and service mode MP1 digital carriers. Figure 1 illustrates digital carriers at -20 dBc and the FCC and iBiquity emission masks. The IBOC analog to digital carrier ratio is shown in a resolution test bandwidth of 1 kHz, which is far less than the total integrated power bandwidth of 140 kHz for the digital carriers. The -41.46 dBc ratio indicated in Figure 1 is calculated from the desired -20 dBc total integrated power ratio as follows:

$$P_{RBW\ Test} = P_{Total} - (10 \text{ Log}_{10}(RBW_{Test} / RBW_{Total}))$$

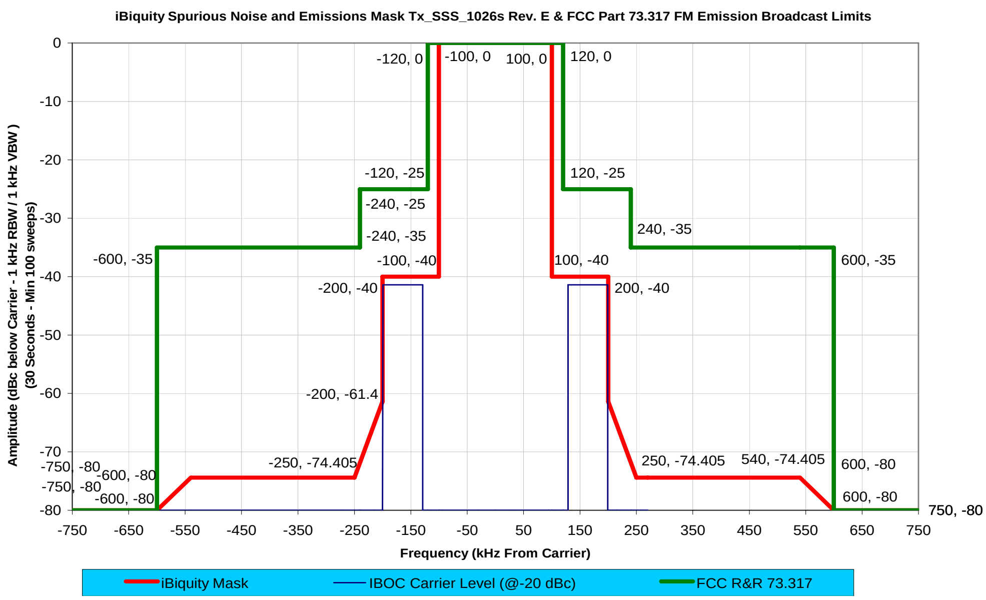


Figure 1 - FM Hybrid IBOC Spectral Test Mask @ -20 dBc

Figure 2 shows the RF spectrum from the forward sample port of a dual-input antenna, and the iBiquity spurious noise and emissions mask. The FCC Part 73.317 emission limit mask is not shown, as the iBiquity mask meets the FCC specification by a large margin.

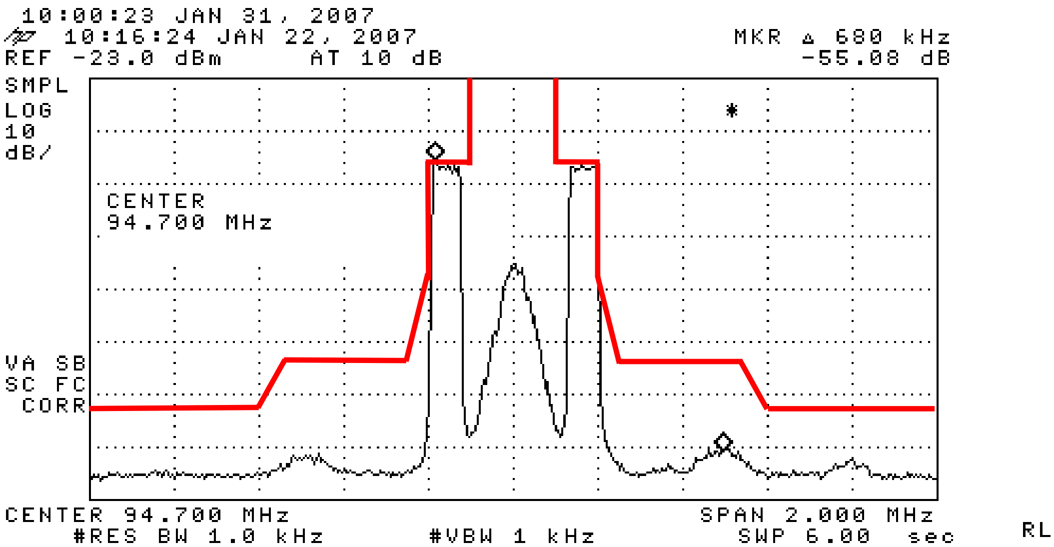


Figure 2 – Typical FM Hybrid IBOC Spectrum @ -20 dBc

Figure 3 shows the digital carriers at 10 dB below analog power levels with both the FCC and iBiquity masks. The digital sidebands will exceed the current iBiquity mask by about 8.5 dB. The digital sidebands comply with the FCC mask.

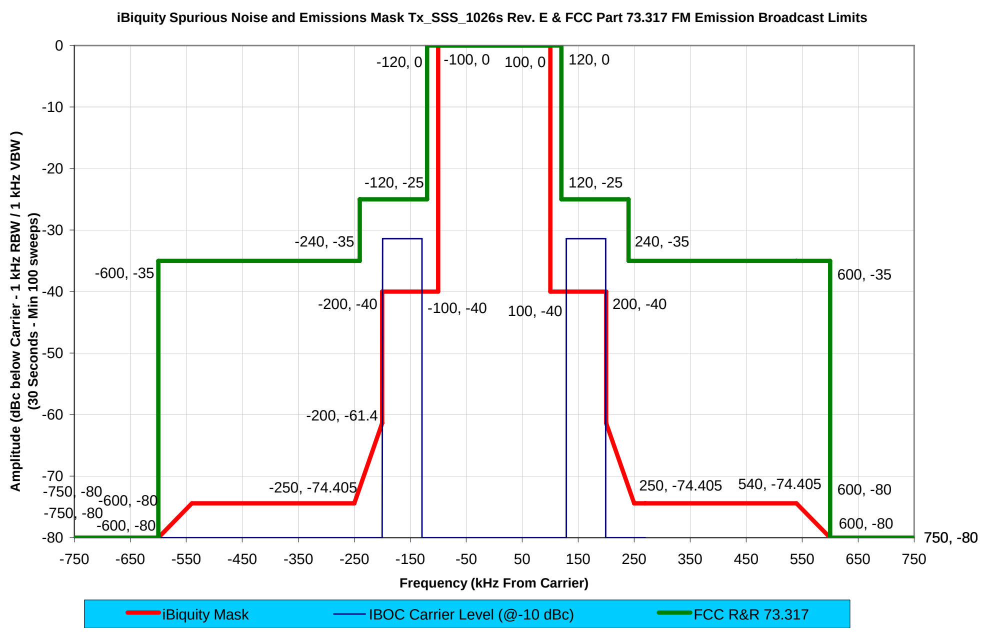


Figure 3 - FM Hybrid IBOC Spectral Test mask @ -10 dBc

Figure 4 shows the RF spectrum from the same sample point as Figure 2. As shown in Figure 3, the sideband power exceeds the current iBiquity digital mask in the frequency range of 6129 to 6199 kHz. Even at the -10 dB power level, the IBOC transmitter is capable of meeting or exceeding the iBiquity mask thresholds established for the -20 dB power level.

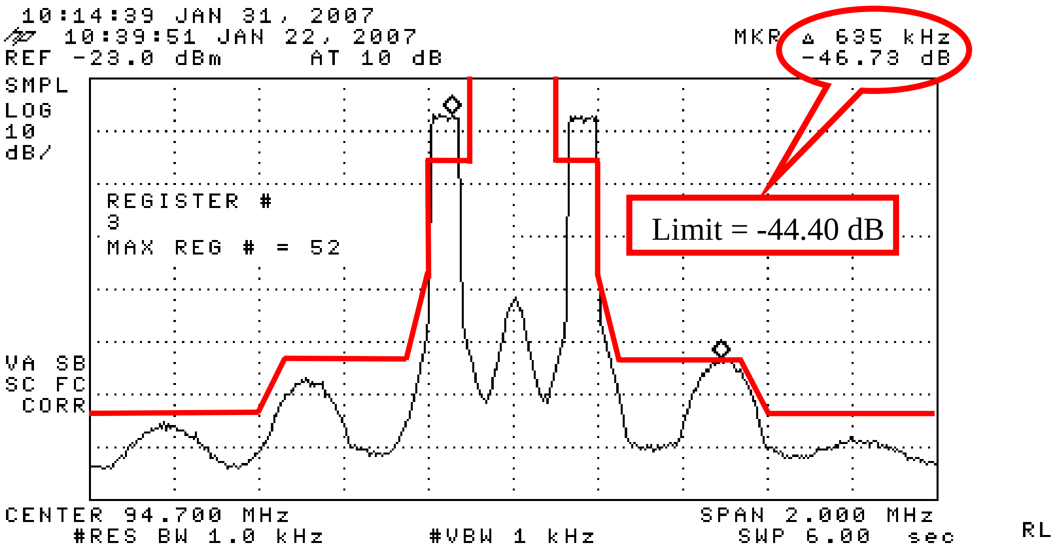


Figure 4 – Typical FM Hybrid IBOC Spectrum @ -10 dBc

1.2 Transmitter Test Sites

These tests were conducted using five stations that were selected to be representative of typical implementations in diverse geographic locations. The tests were conducted in the Northeast, Midwest and Western United States with various terrain profiles. All stations except for one are licensed as Class B stations but have different antenna heights and effective radiated power. Table 1 summarizes station information.

Call Sign	Freq MHz	City	St.	Cl	Power Combine Method	Latitude	Longitude	Analog ERP Watts	IBOC ERP @-20 dBc Watts	IBOC ERP @-10 dBc Watts	AGL m	GL m	AMSL m	HAAT m
WCSX	94.7	Detroit	MI	B	Dual Input Antenna	N42-27-13	W83-09-50	13500	135	1350	287	201	488	289.56
WKCI	101.3	New Haven	CT	B	Space Combined Antenna	N41-26-01	W72-56-45	12000	Analog Antenna		177	202	379	277.03
								IBOC Ant	90	900	154	202	356	254.03
KOST	103.5	Los Angeles	CA	B	Space Combined Antenna	N34-13-32	W118-03-52	12500	Analog Antenna		137	1706	1843	959.62
								IBOC Ant	42	420	46	1706	1752	868.62
KROQ	106.7	Los Angeles	CA	B	Common Amplifier	N34-09-50	W118-11-46	6500	65	650	86	531	617	231.34
WDHA	105.5	Dover	NJ	A	Space Combined Antenna	N40-51-19	W74-30-42	1000	Analog Antenna		96	258	354	177.03
								IBOC Ant	10	100	92	258	350	173.03
WJRZ	100.1	Manahawkin	NJ	A	Common Amplifier	N39-47-54	W74-12-10	1700	17	2 Input IBOC In	143	6	149	138.74
					Dual Input Antenna				Same Amp	170				
WRAT	95.9	Point Pleasant	NJ	A	Dual Input Antenna	N40-10-15	W74-01-42	4000	40	400	88	2	90	80.53

Table 1 – Transmitter Site Information

1.3 Operating Power

For these tests, iBiquity chose to operate each transmitting facility at total power levels of 20 dB and 10 dB below that of the reference analog carrier. The digital to analog power ratio was verified with spectrum analysis in the field as shown in Figure 5.

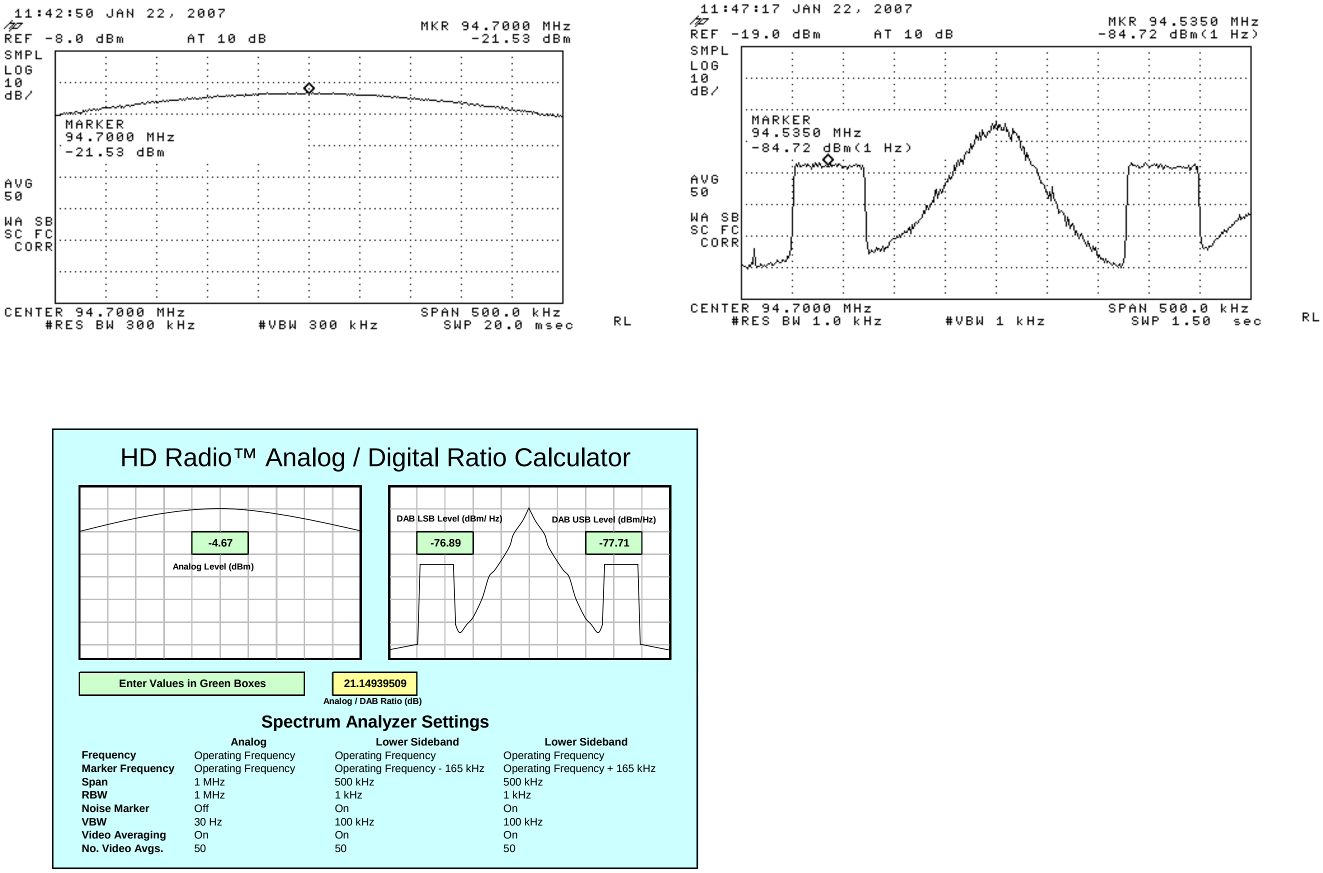


Figure 5 – Operating Power Calculation (Field)

1.3.1 Calculations

The digital to analog ratio was calculated from two spectral shots: One at 300 kHz RBW/VBW (for analog power) and one at 1 kHz RBW/VBW, with the noise marker turned on (dBm/Hz for digital power). The value of the noise marker was multiplied out as a voltage to 70 kHz for each sideband and the log or the product taken. These two values were added in the same way and the total power in 140 kHz was obtained. The analog power was then subtracted from this value to obtain the ratio in dB.

1.4 Station Configuration

Three analog / digital power combining methods were used to transmit the hybrid IBOC signal:

1. Common Amplification (KROQ & WJRZ @ -20 dBc)

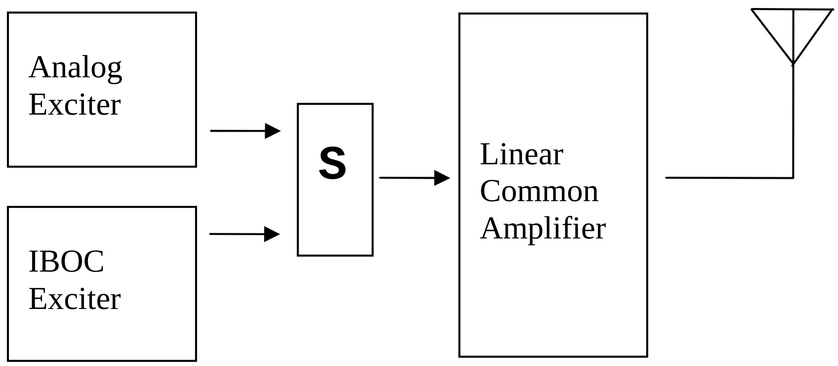


Figure 6 – Common Amplification (Low Level Combining)

2. Space Combined Dual Antenna (WKCI, KOST & WDHA)

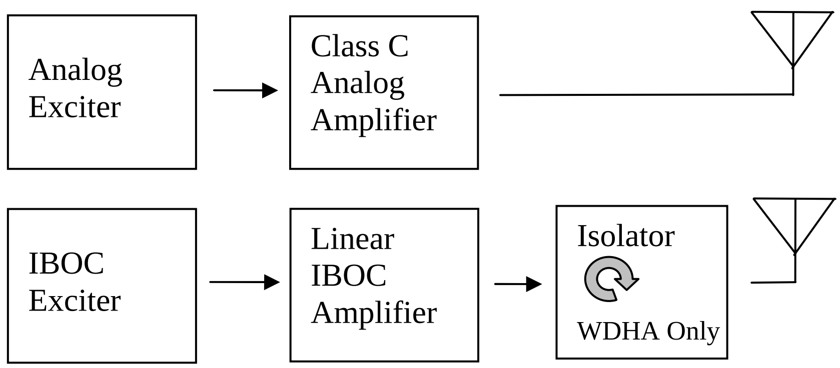


Figure 7 – Dual Antenna (Space Combined)

3. Dual Input Antenna (WCSX, WJRZ @ -10 dBc & WRAT)

   (Note: The Analog Isolator was not necessary at WJRZ and WRAT)

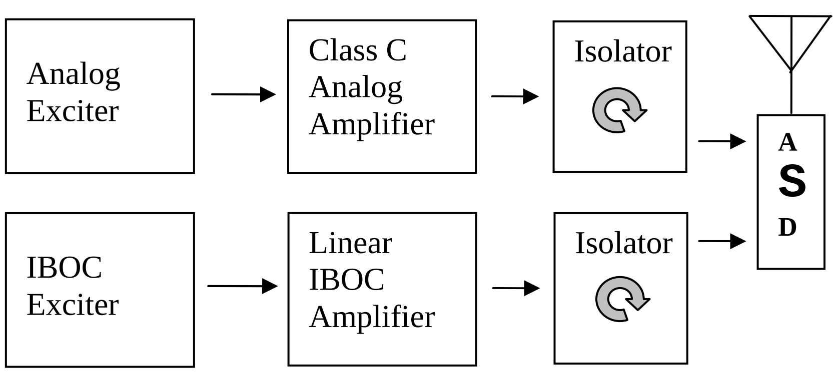


Figure 8 – Dual Input Antenna

1.5 Van Configuration

The mobile test platform used to collect field test data was identical in equipment and configuration to those used for previous iBiquity tests such as those conducted in 2002 in conjunction with the National Radio Systems Committee. The receiver used was a typical off the shelf consumer after market car radio (JVC KD-HDR1 – Serial # 161X1547)

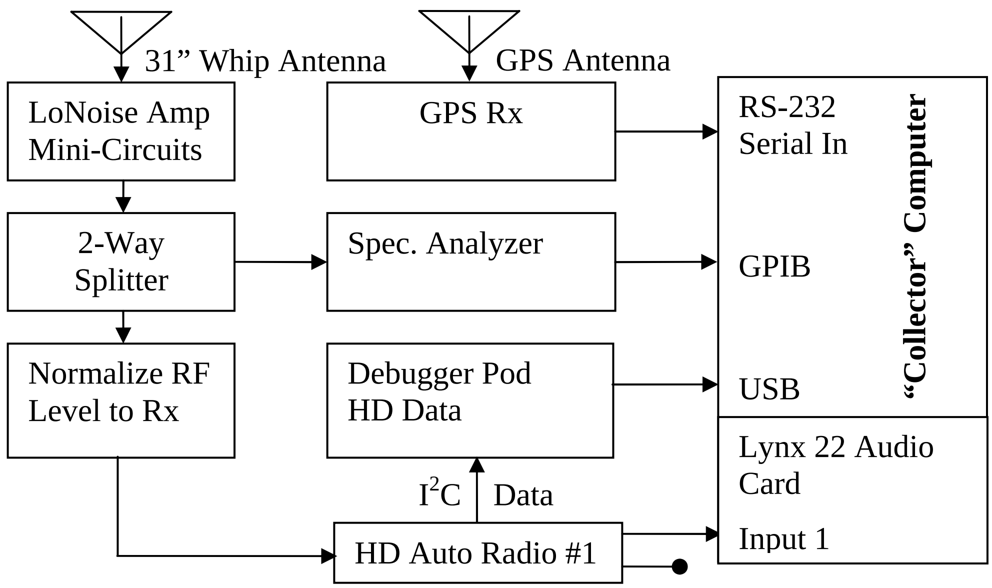


Figure 9 – Mobile Test Platform

1.6 Route Selection

For WCSX and WDHA, four routes most closely approximating radials from the transmitter were chosen. For WKCI, three routes were chosen, as Long Island Sound blocks access to the South. In Los Angeles, for KOST and KROQ, because of the terrain and population profile, it was decided to run a somewhat circular route around the city, to best characterize improvements in coverage on the major interstates. In the case of WJRZ & WRAT, circular loops were chosen to maximize the area characterized.

2 Test Results

2.1 WCSX, Detroit, MI (Page 14)

A 10 dB digital power increase augmented WCSX's coverage area by 74%. Due largely to the flat terrain profile of the Detroit area, the RF signal was generally not shadowed. The increased power offered an unimpaired 33% distance improvement in solid digital reception to the Northeast, and the signal carried 47% further to the south, despite the presence of a single powerful first adjacent interferer. The signal suffered somewhat to the West and more to the Northwest, hampered by dual first adjacent interferers.

Station	WCSX	**Extent of Solid Digital Coverage**				**Distance to Point of Digital Failure**			
City	Detroit. MI	**-20 dBc**	**-10 dBc**	**Improvement**		**-20 dBc**	**-10 dBc**	**Improvement**	
Radial		**km**	**km**	**km**	**%**	**km**	**km**	**km**	**%**
West (Rt. 96)		38	50	12	32	50	61	11	22
Northwest (Rt. 75)		44	49	5	11	49	59	10	20
Northeast (Rt. 94)		60	80	20	33	60	85	25	42
South (Rt. 75)		47	69	22	47	52	89	37	71
Avg	**Distance in km (Actual)**	47	62	15	31	53	74	21	39
	Area in km^2 (Dist^2 * π) (Actual)	6936	12070	5062	74	8820	17195	8375	95

Table 2 – WCSX Performance

2.2 WKCI, New Haven, CT (Pages 15 & 16)

The New Haven, Connecticut area is characterized by hilly terrain, which causes terrain shadowing in some directions, but also mitigates some first adjacent interference. Operating the system with digital power of -10 dB improved the solid digital coverage radius by approximately 26%, which translates to a 62% increase in area. It is worthy of note that dropouts in the digital coverage of metropolitan Hartford, Connecticut (a "rimshot" for WKCI) were largely eliminated by the power increase.

Station	WKCI	**Extent of Solid Digital Coverage**				**Distance to Point of Digital Failure**			
City	New Haven, CT	**-20 dBc**	**-10 dBc**	**Improvement**		**-20 dBc**	**-10 dBc**	**Improvement**	
Radial		**km**	**km**	**km**	**%**	**km**	**km**	**km**	**%**
North (Rt. 91N)		72	93	21	29	76	93	17	22
East (Rt. 95N)		57	71	14	25	69	90	21	30
West (Rt. 95S)		25	31	6	24	28	41	13	46
Avg	**Distance in km (Actual)**	51	65	14	26	58	75	17	33
	Area in km^2 (Dist^2 * π) (Actual)	8167	13267	5100	62	10563	17664	7101	67

Table 3 – WKCI Performance

2.3 KOST, Los Angeles, CA (Page 17)

Solid digital coverage for KOST improved in distance by 24% and area by 58%, enabling unimpaired multicast reception in significant markets such as Thousand Oaks, Ontario and San Clemente. It is worthy of note that coverage along Interstate 405 in the Longbeach, California area was somewhat "spotty" at -20 dBc and solid at -10 dBc. The performance at -20 may be due to the AGL height difference of 91 meters between KOST's analog (main) and digital (auxiliary) antennas. Terrain shadowing in a number of directions caused total loss of signal at either power level.

Station	KOST	**Extent of Solid Digital Coverage**				**Distance to Point of Digital Failure**			
City	Los Angeles, CA	**-20 dBc**	**-10 dBc**	**Improvement**		**-20 dBc**	**-10 dBc**	**Improvement**	
Radial		**km**	**km**	**km**	**%**	**km**	**km**	**km**	**%**
Northeast (Rt. 5)		12	16	4	33	21	56	35	167
Northwest (Rt. 101)		50	60	10	20	60	71	11	18
Southwest (Rt. 405)		62	89	27	44	76	105	29	38
Southeast (Rt. 10)		30	30	0	0	34	103	69	203
Avg	**Distance in km (Actual)**	39	49	10	24	48	84	36	107
	Area in km^2 (Dist^2 * π) (Actual)	4776	7539	2763	58	7235	22156	14921	206

Table 3 – KOST Performance

2.4 KROQ, Los Angeles, CA (Page 18)

KROQ's digital coverage improved toward Ontario and Thousand Oaks, California, but not as dramatically as that for KOST. Terrain shadowing for KROQ is exacerbated are due to the location of the transmitter, which is farther to the West, at a lower antenna height.

Station	KROQ	**Extent of Solid Digital Coverage**				**Distance to Point of Digital Failure**			
City	Los Angeles	**-20 dBc**	**-10 dBc**	**Improvement**		**-20 dBc**	**-10 dBc**	**Improvement**	
Radial		**km**	**km**	**km**	**%**	**km**	**km**	**km**	**%**
NorthEast (Rt. 5)		27	27	0	0	35	35	0	0
NorthWest (Rt. 101)		59	66	7	12	51	91	40	78
SouthWest (Rt. 405)		79	87	8	10	79	99	20	25
SouthEast (Rt. 10)		38	53	15	39	110	112	2	2
Avg	**Distance in km (Actual)**	51	58	8	15	69	84	16	26
	Area in km^2 (Dist^2 * π) (Actual)	8167	10563	2396	29	14950	22156	7206	48

Table 4 – KROQ Performance

2.5 WDHA, Dover, NJ (Page 19)

WDHA is a Class "A" FM facility, with its power derated from 3 kW to 1 KW because of the elevated transmitter location. WDHA takes advantage of local terrain for increasing its antenna height, but also has its signal shadowed by the same topography. Coverage improvements with high power can be seen to the West and the South, but as is the case in Los Angeles, mountains and road cuts to the North and East caused an instantaneous loss of both analog and digital signal, at any power level.

<table>
<tr><th>Station</th><th colspan="2">WDHA</th><th colspan="4">Extent of Solid Digital Coverage</th><th colspan="4">Distance to Point of Digital Failure</th></tr>
<tr><th>City</th><th colspan="2">Dover, NJ</th><th>-20 dBc</th><th>-10 dBc</th><th colspan="2">Improvement</th><th>-20 dBc</th><th>-10 dBc</th><th colspan="2">Improvement</th></tr>
<tr><th colspan="3">Radial</th><th>km</th><th>km</th><th>km</th><th>%</th><th>km</th><th>km</th><th>km</th><th>%</th></tr>
<tr><td colspan="3">North (Rt. 287)</td><td>18</td><td>19</td><td>1</td><td>6</td><td>19</td><td>20</td><td>1</td><td>5</td></tr>
<tr><td colspan="3">South (Rt. 287)</td><td>9</td><td>10</td><td>1</td><td>11</td><td>19</td><td>31</td><td>12</td><td>63</td></tr>
<tr><td colspan="3">West (Rt. 80)</td><td>12</td><td>16</td><td>4</td><td>33</td><td>17</td><td>25</td><td>8</td><td>47</td></tr>
<tr><td colspan="3">East (Rt. 80)</td><td>20</td><td>22</td><td>2</td><td>10</td><td>22</td><td>22</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Avg</td><td colspan="2">Distance in km (Actual)</td><td>15</td><td>17</td><td>2</td><td>15</td><td>19</td><td>25</td><td>5</td><td>29</td></tr>
<tr><td colspan="2">Area in km^2 (Dist^2 * π) (Actual)</td><td>707</td><td>907</td><td>200</td><td>28</td><td>1134</td><td>1963</td><td>829</td><td>73</td></tr>
</table>

Table 5 – WDHA Performance

2.6 WJRZ, Manahawkin, NJ (Pages 20 thru 23)

WJRZ is a Class "A" FM facility, with its power derated from 3 kW to 1.7 KW due to an antenna height greater than 100 meters. WJRZ's service area is characterized by a relatively flat topography. A 10 dB digital power increase augmented WJRZ's coverage area by over 100% over flat, largely unshadowed terrain. The increased power offered an unimpaired average overall 46% distance improvement in solid HD reception.

<table>
<tr><th>Station</th><th>WJRZ</th><th colspan="4">Radius of Solid Digital Coverage</th><th colspan="4">Radius to Point of Digital Failure</th></tr>
<tr><th>City</th><th>Point Pleasant, NJ</th><th>-20 dBc</th><th>-10 dBc</th><th colspan="2">Improvement</th><th>-20 dBc</th><th>-10 dBc</th><th colspan="2">Improvement</th></tr>
<tr><th colspan="2">Loop</th><th>km</th><th>km</th><th>km</th><th>%</th><th>km</th><th>km</th><th>km</th><th>%</th></tr>
<tr><td colspan="2" rowspan="2">North
(Garden St. Pkwy., Rt. 35 & Rt. 9)</td><td>22</td><td>35</td><td>13</td><td>70</td><td>30</td><td>45</td><td>15</td><td>50</td></tr>
<tr><td>23</td><td>37</td><td>14</td><td>61</td><td>25</td><td>42</td><td>17</td><td>68</td></tr>
<tr><td colspan="2" rowspan="2">West (Rt. 72, Rt. 70, Rt. 37 & Rt. 9)</td><td>26</td><td>28</td><td>2</td><td>7</td><td>21</td><td>33</td><td>14</td><td>57</td></tr>
<tr><td>19</td><td>30</td><td>11</td><td>58</td><td>19</td><td>30</td><td>11</td><td>58</td></tr>
<tr><td colspan="2" rowspan="2">South
(Garden St. Pkwy., Rt. 532 & Rt. 9)</td><td>25</td><td>35</td><td>10</td><td>40</td><td>25</td><td>42</td><td>17</td><td>68</td></tr>
<tr><td>23</td><td>32</td><td>9</td><td>39</td><td>24</td><td>40</td><td>16</td><td>67</td></tr>
<tr><td rowspan="4">Avg.</td><td>Distance in km (Actual)</td><td>23</td><td>33</td><td>10</td><td>46</td><td>24</td><td>39</td><td>15</td><td>63</td></tr>
<tr><td>Area in km^2 (Dist^2 * π) (Actual)</td><td>1661</td><td>3419</td><td>1758</td><td>105</td><td>1809</td><td>4776</td><td>2967</td><td>164</td></tr>
<tr><td>Distance in km (Predicted)</td><td>18</td><td>31</td><td>13</td><td>72</td><td>30</td><td>45</td><td>15</td><td>50</td></tr>
<tr><td>Area in km^2 (Predicted)</td><td>962</td><td>2909</td><td>1947</td><td>202</td><td>2909</td><td>6417</td><td>3508</td><td>121</td></tr>
</table>

Table 6 – WJRZ Performance

2.7 WRAT, Point Pleasant, NJ (Pages 24 thru 27)

WRAT is a Class “A” FM facility, with its power increased from 3 kW to 4 KW due to reduced antenna height. WRAT’s service area is characterized by a relatively flat topography. WRAT’s service area is characterized by a relatively flat topography. A 10 dB digital power increase augmented WRAT’s coverage area by over 67% (the improvement was probably not as great as for WJRZ, because WRAT’s antenna is lower and the signal is more likely to be shadowed by small terrain variations). The increased power offered an unimpaired average overall 29% distance improvement in solid HD reception.

Station	WRAT	**Extent of Solid Digital Coverage**				**Distance to Point of Digital Failure**			
City	Point Pleasant, NJ	**-20 dBc**	**-10 dBc**	**Improvement**		**-20 dBc**	**-10 dBc**	**Improvement**	
Loop		**km**	**km**	**km**	**%**	**km**	**km**	**km**	**%**
North (Garden St. Pkwy., Rt. 35, Rt. 36 & Rt. 71)		25	30	5	20	30	40	10	33
		25	27	2	8	30	40	10	33
West (Rt. 195, Rt. 537, Rt. 539 & Rt. 70)		22	28	6	27	25	31	6	24
		23	27	4	17	35	39	4	11
South (Garden St. Pkwy., Rt. 9 & Rt. 37 & Rt. 35)		25	38	13	52	28	47	9	68
		23	34	11	48	32	45	8	41
Avg.	**Distance in km (Actual)**	24	31	7	29	30	40	10	33
	Area in km^2 (Dist^2 * π) (Actual)	1809	3018	1209	67	2826	5024	2198	78
	Distance in km (Predicted)	10	16	6	60	16	23	7	44
	Area in km^2 (Predicted)	952	2505	1553	163	2505	4749	2244	90

Table 7 – WRAT Performance

2.8 Area and Population Studies

Studies were done on WJRZ and WRAT in order to characterize the predicted improvement in area and population resulting from a 10 dB digital power increase. For both stations, a field intensity matrix was generated using ComStudy 2.0® Software with a Longley-Rice 90/90 model at 6” of resolution. The field intensity plots were color coded at 30, 40 and 50 dBu. Previous test runs have validated a model that predicts the following receiver performance: (A validation of this model may be seen on pages 22, 23, 26 & 27)

	Color Code	**Analog**	**Intermittent HD**		**Solid HD**	
			-20 dBc	**-10 dBc**	**-20 dBc**	**-10 dBc**
< 30 dBu	**Gray**					
Þ 30 dBu < 40 dBu	**Dark Blue**	**X**		**X**		
Þ 40 dBu < 50 dBu	**Light Blue**	**X**	**X**			**X**
> 50 dBu	**White**	**X**			**X**	**X**

Table 8 – Propagation Prediction Color Code

A population count based on the 2000 census was then applied to the matrix. As can be seen in the charts below, there is a two to threefold increase in area and even larger gains in population by increasing the digital power by 10 dB.

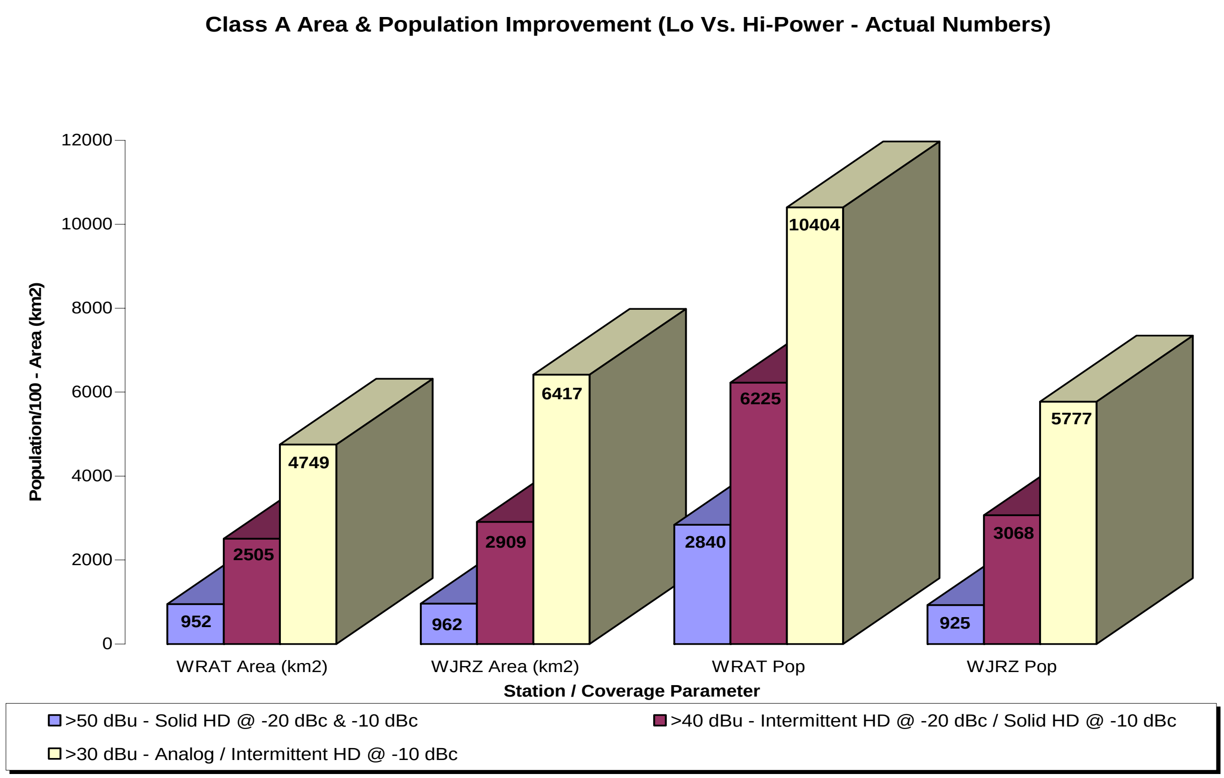


Figure 10 – WJRZ & WRAT – Area and Population

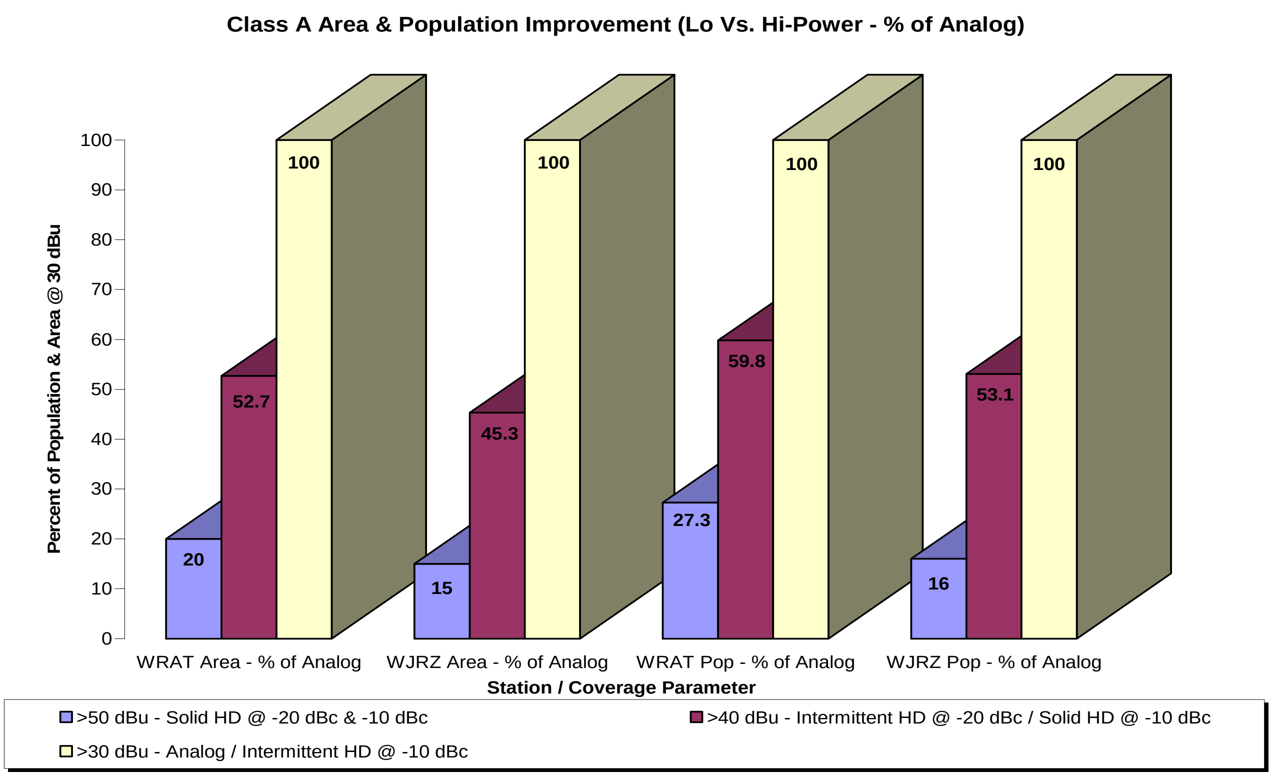


Figure 11 – WJRZ & WRAT – Area and Population Improvement

3 Field Test Summary

Aggregating all data for each class of operation yields the following:

3.1 Class B Performance (Measured)

Call Sign	Freq (MHz)	City	Solid HD Radius @-20 dBc (Kilometers)	Solid HD Radius @-10 dBc (Kilometers)	Radius Gain -20 to -10 dBc (kilometers)	Radius Gain -20 to -10 dBc (Percent)	Area Gain -20 to -10 dBc (kilometers^2)	Area Gain -20 to -10 dBc (Percent)
WCSX	94.7	Detroit	47	62	15	31	5062	74
WKCI	101.3	New Haven	51	65	14	26	5100	62
KOST	103.5	Los Angeles	39	49	10	24	2763	58
KROQ	106.7		51	58	8	15	2396	29
Averages			47	59	12	24	3830	56

3.2 Class A Performance (Measured)

Call Sign	Freq (MHz)	City (All in NJ)	Solid HD Radius @-20 dBc (Kilometers)	Solid HD Radius @-10 dBc (Kilometers)	Radius Gain -20 to -10 dBc (kilometers)	Radius Gain -20 to -10 dBc (Percent)	Area Gain -20 to -10 dBc (kilometers^2)	Area Gain -20 to -10 dBc (Percent)
WDHA	94.7	Dover	15	17	2	15	200	28
WJRZ	101.3	Manahawkin	23	33	10	46	1758	105
WRAT	106.7	Point Pleasant	24	31	7	29	1209	67
Averages			21	27	6	30	1056	67

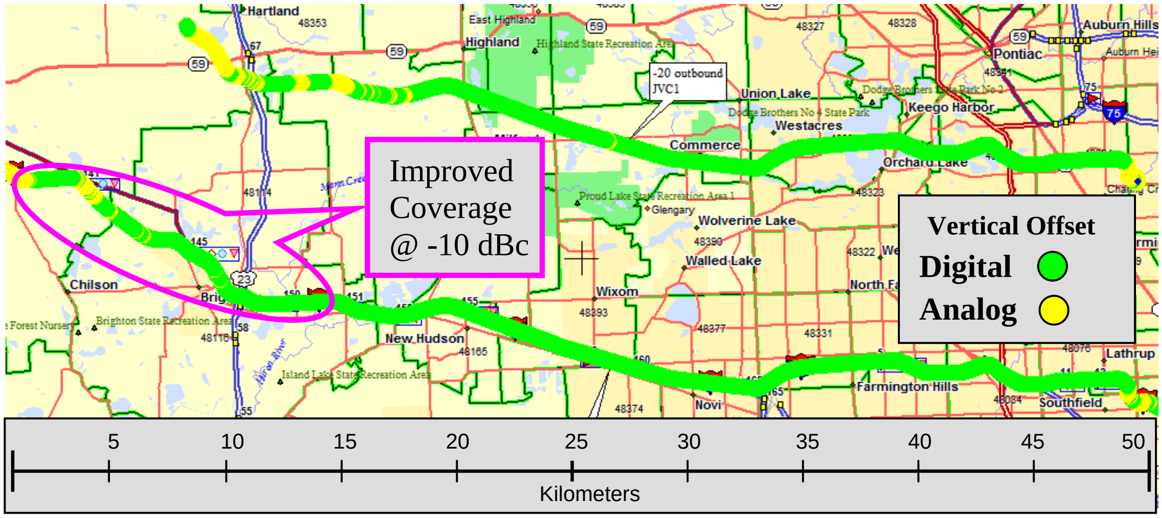
3.3 Class A Performance (Predicted)

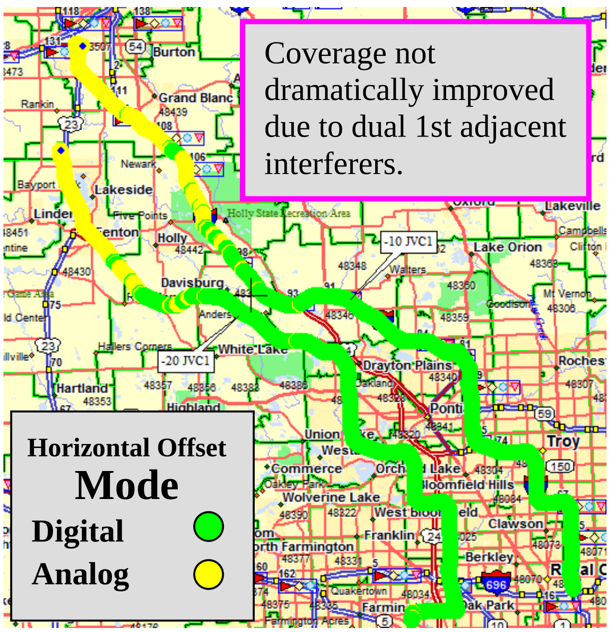
Call Sign	Freq (MHz)	City (All in NJ)	Solid HD Radius @-20 dBc (Kilometers)	Solid HD Radius @-10 dBc (Kilometers)	Radius Gain -20 to -10 dBc (kilometers)	Radius Gain -20 to -10 dBc (Percent)	Area Gain -20 to -10 dBc (kilometers^2)	Area Gain -20 to -10 dBc (Percent)
WJRZ	101.3	Manahawkin	18	31	13	72	1947	202
WRAT	106.7	Point Pleasant	10	16	6	60	1209	67
Averages			14	24	10	71	1578	135

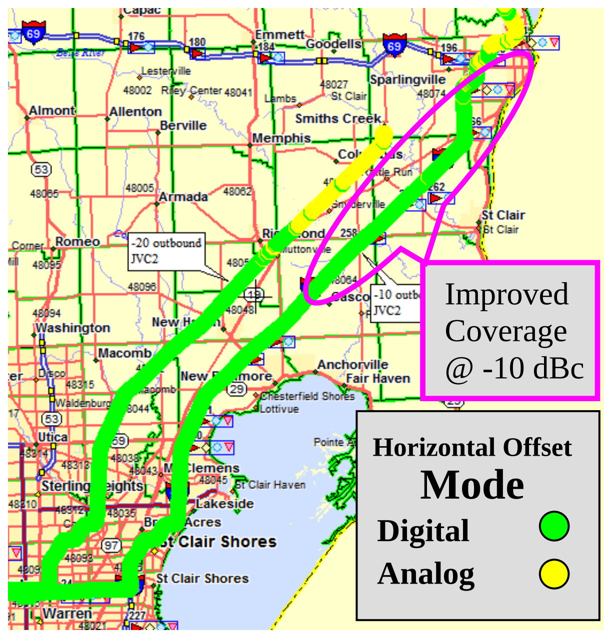
These field test results have demonstrated that a 10 dB increase in the total integrated power of hybrid IBOC digital carriers provides a substantial improvement in far field coverage, as well as improving signal robustness in the stations main coverage area, equaling that of analog.

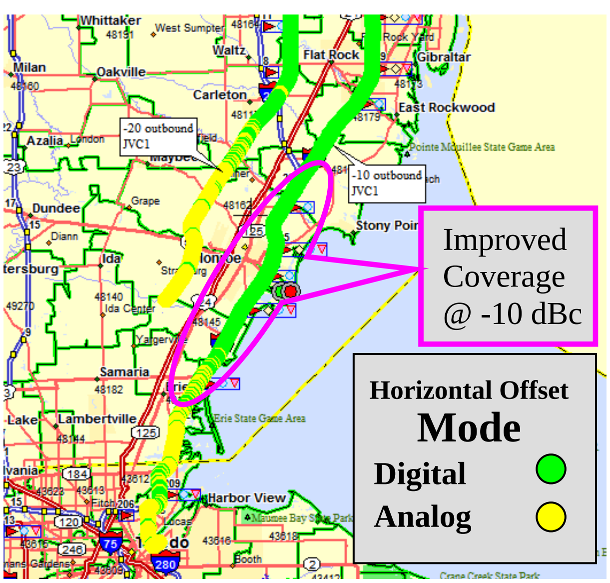
4 Performance Characterization Maps

(Note: Many of these maps have two performance runs plotted on the same map. The actual route at -10 dBc is plotted for WCSX and WKCI, -20 dBc is shown for WDHA. The other run is offset vertically or horizontally according to the legend.)









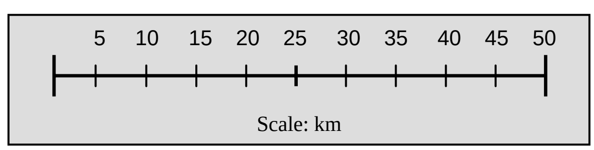


Figure 12 – WCSX Performance

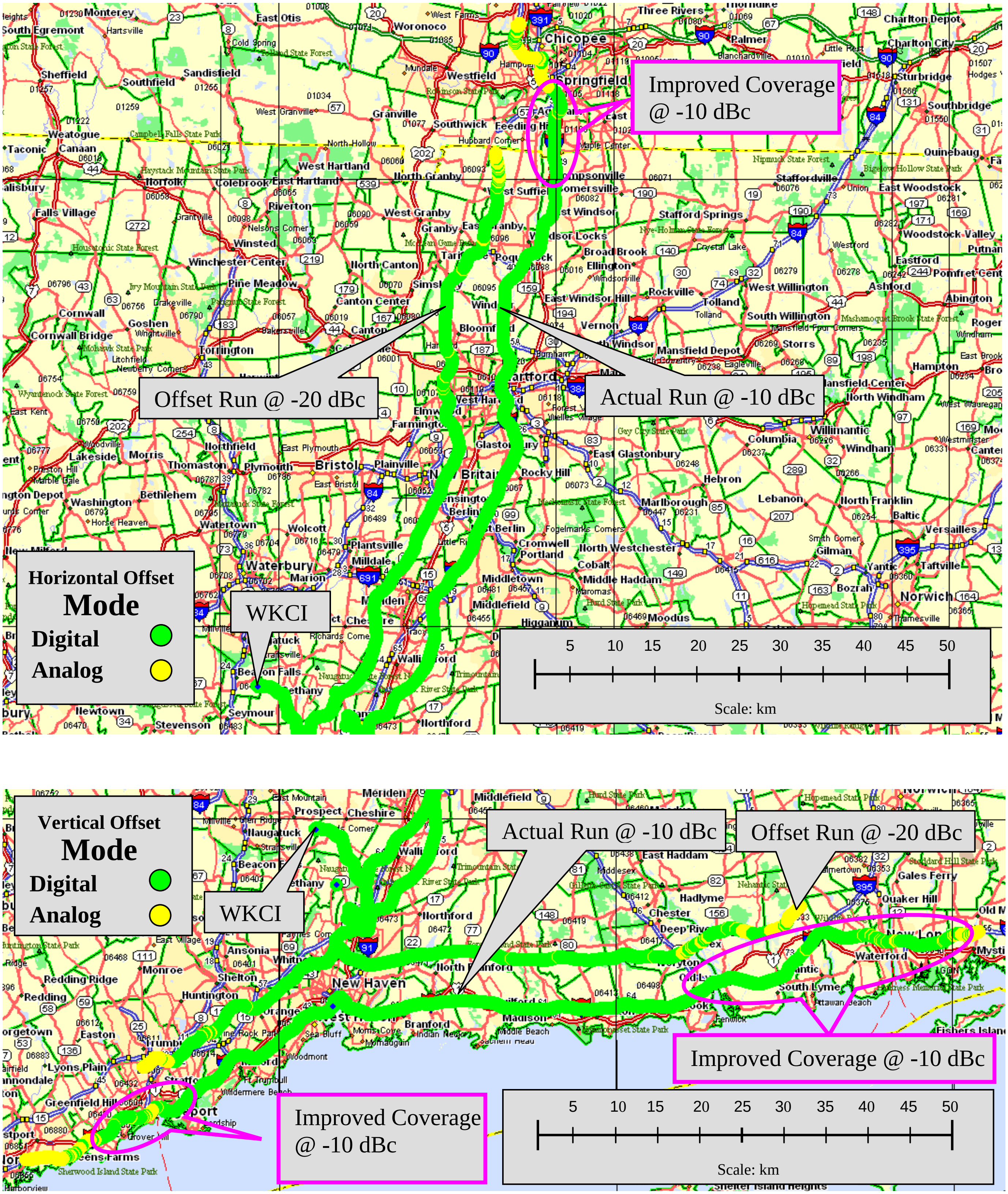


Figure 13 – WKCI Performance

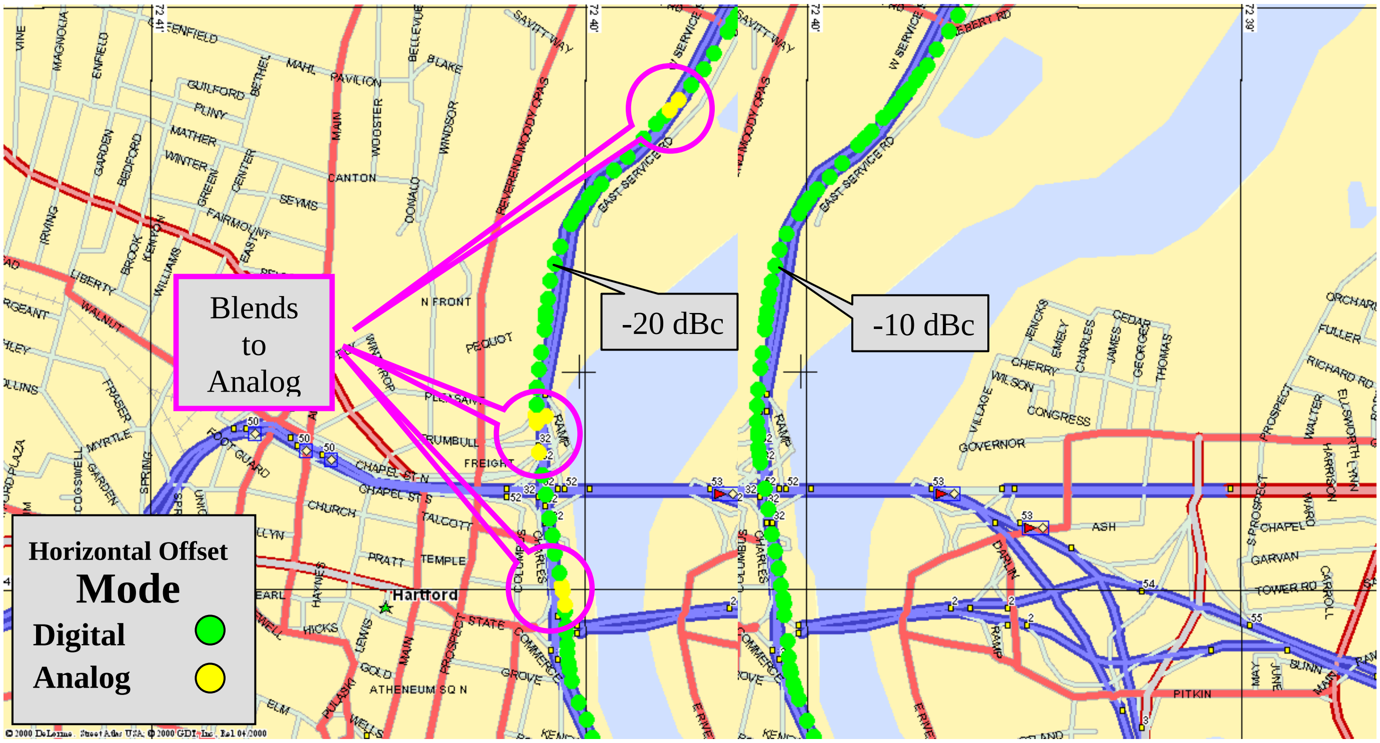


Figure 14 – WKCI Performance in Hartford, CT (Improved Signal Robustness)

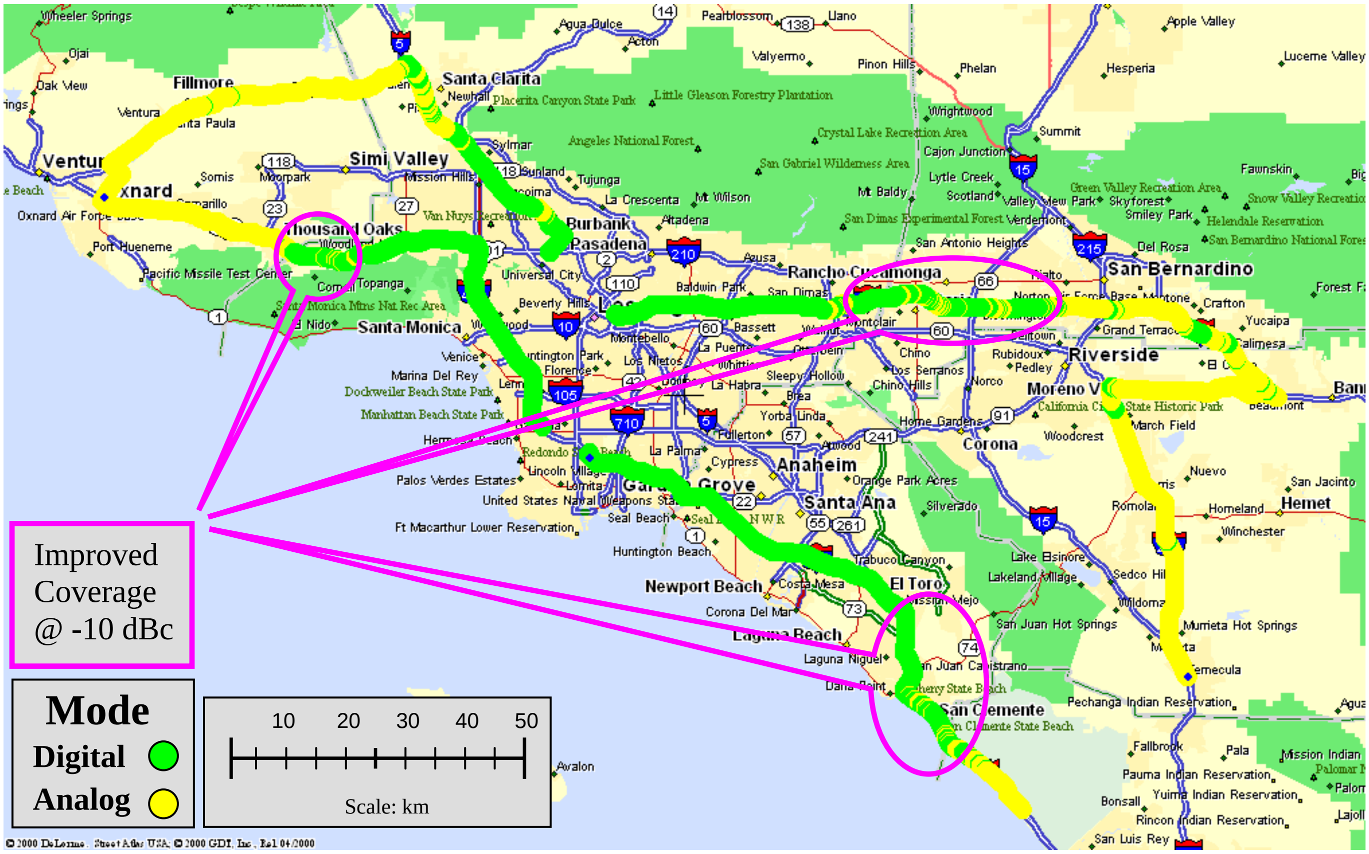


Figure 15 – KOST Performance @ -10 dBc

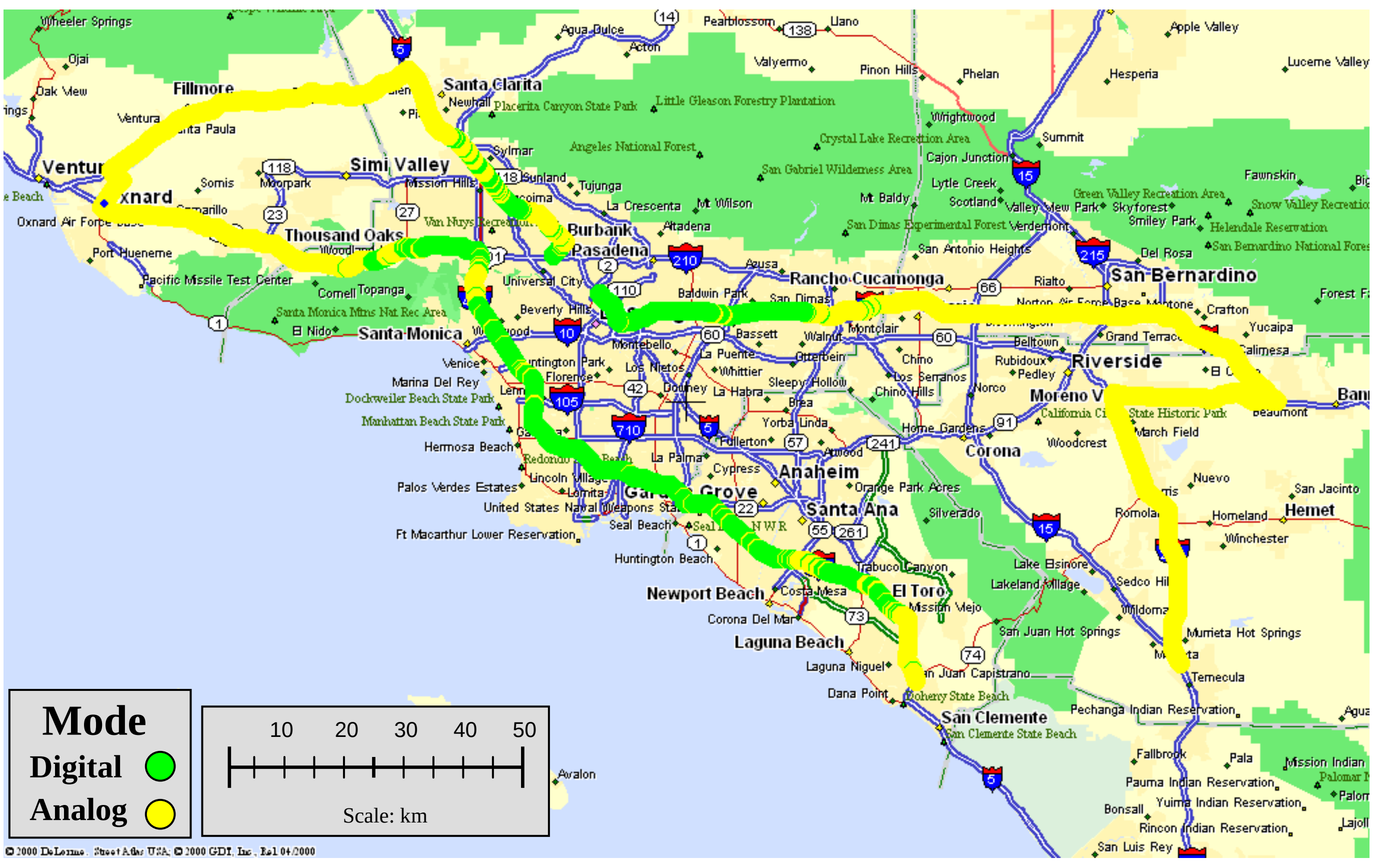


Figure 16 – KOST Performance @ -20 dBc

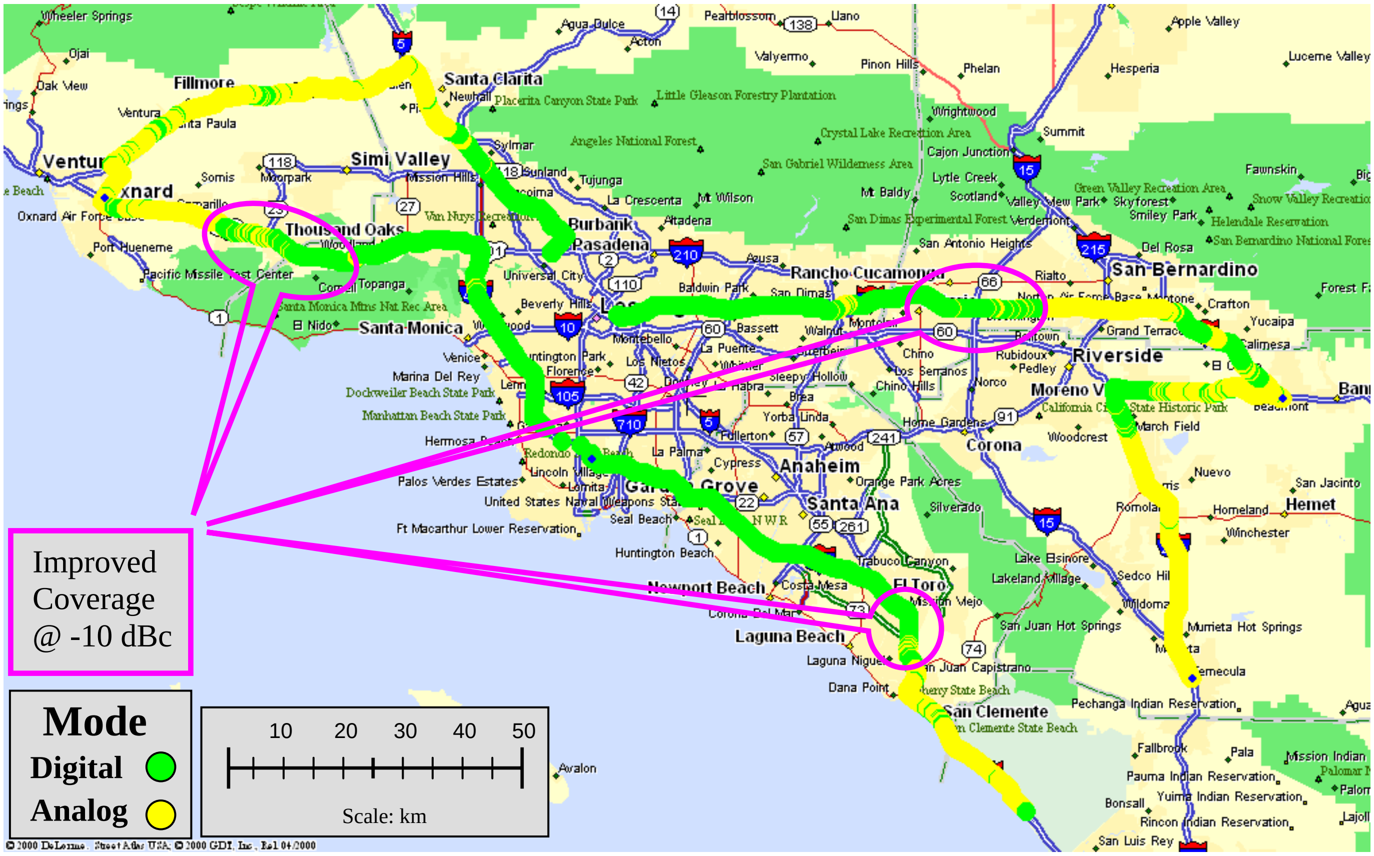


Figure 17 – KROQ Performance @ -10 dBc

Figure 18 – KROQ Performance @ -20 dBc

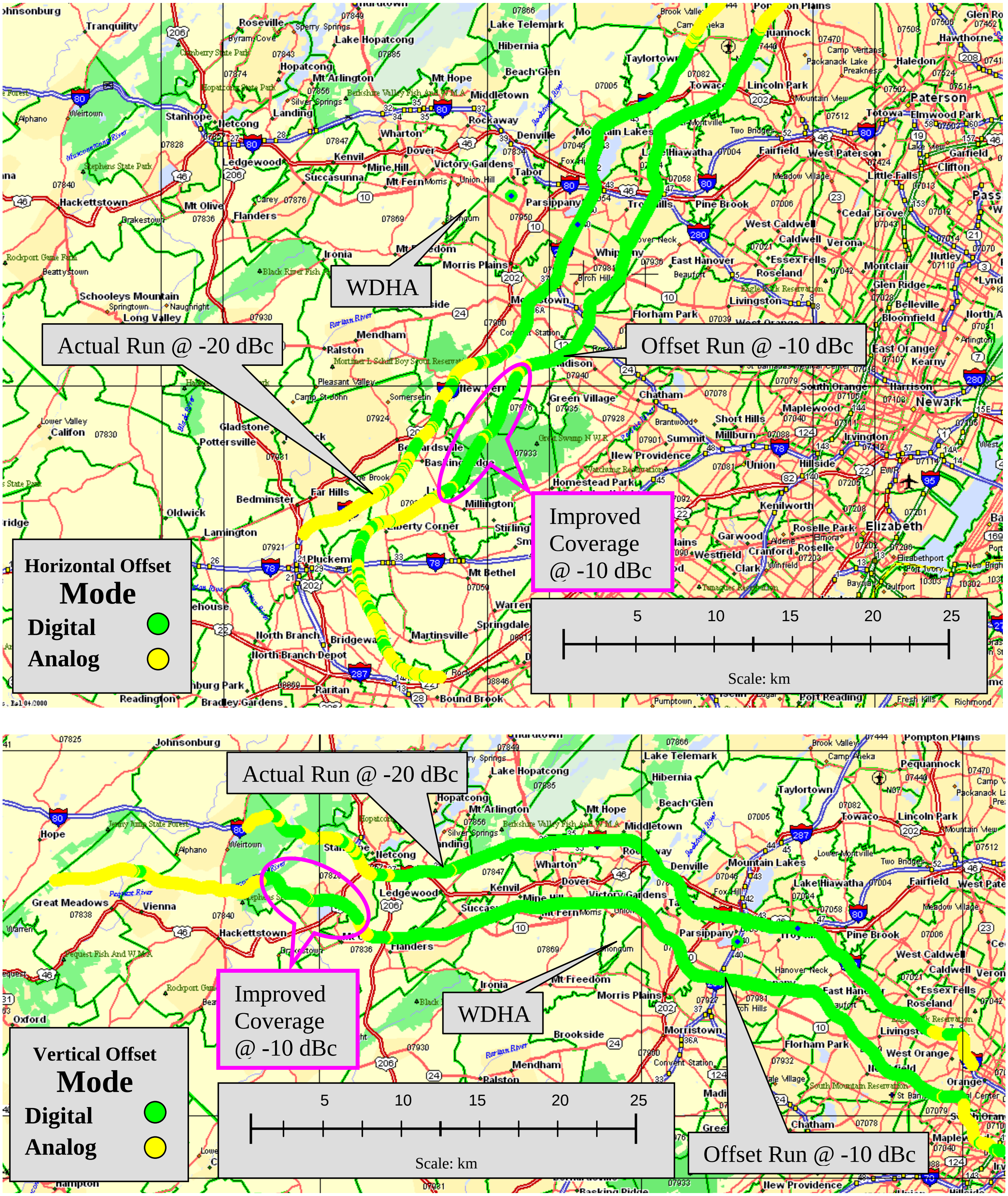


Figure 19 – WDHA Performance

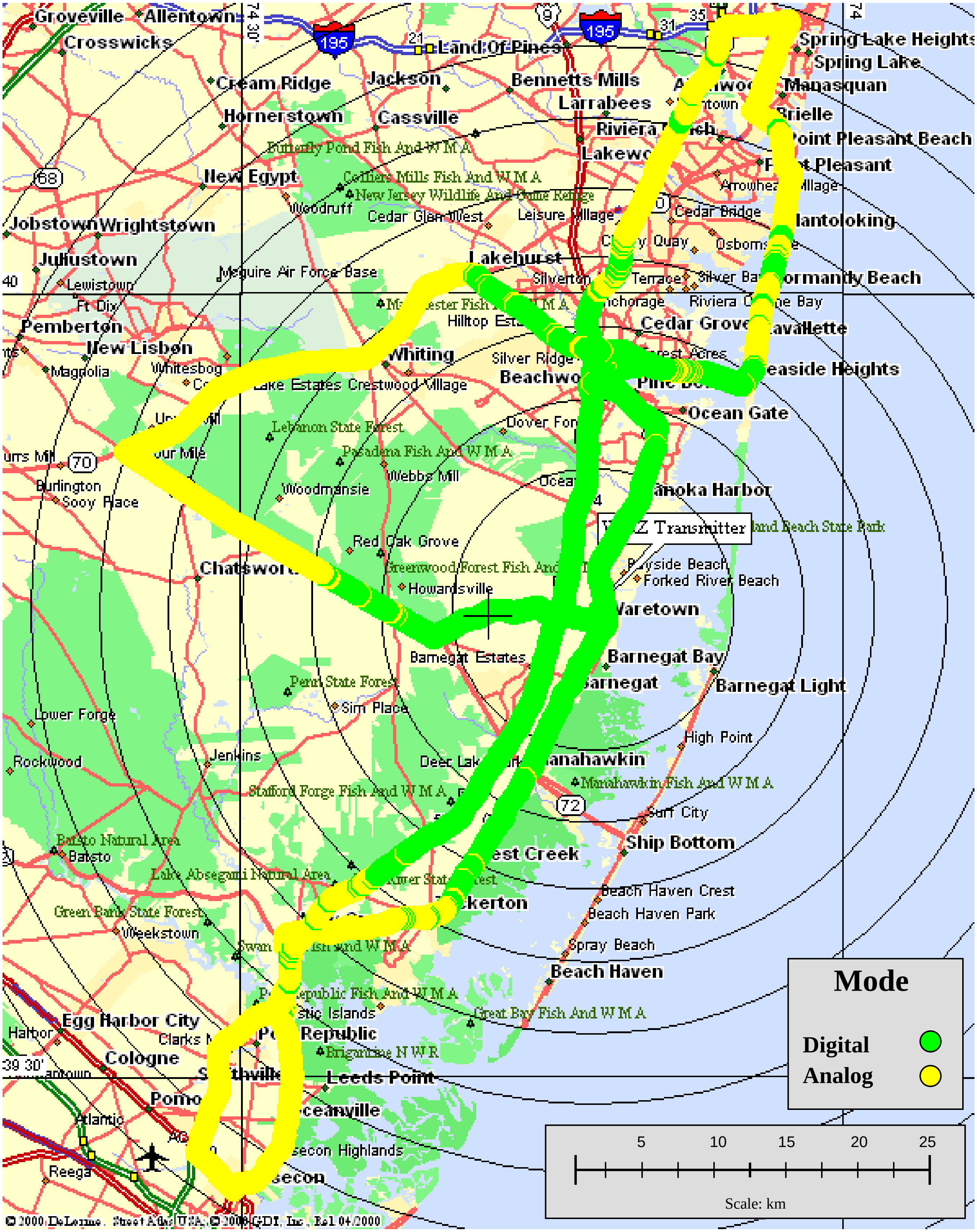


Figure 20 – WJRZ HD Radio™ Coverage @ -20 dBc D/A Power Ratio (All Loops)

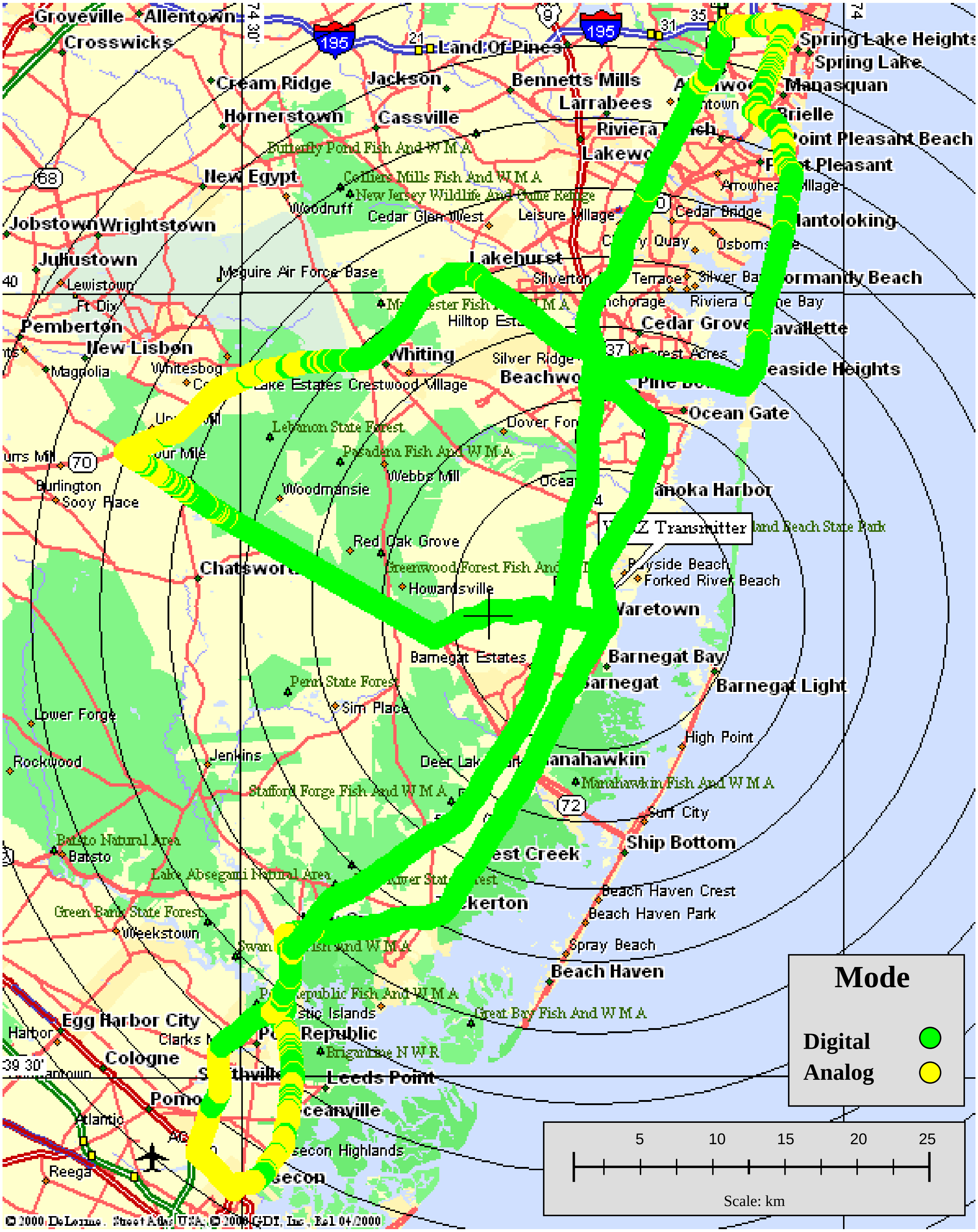


Figure 21 – WJRZ HD Radio™ Coverage @ -10 dBc D/A Power Ratio (All Loops)

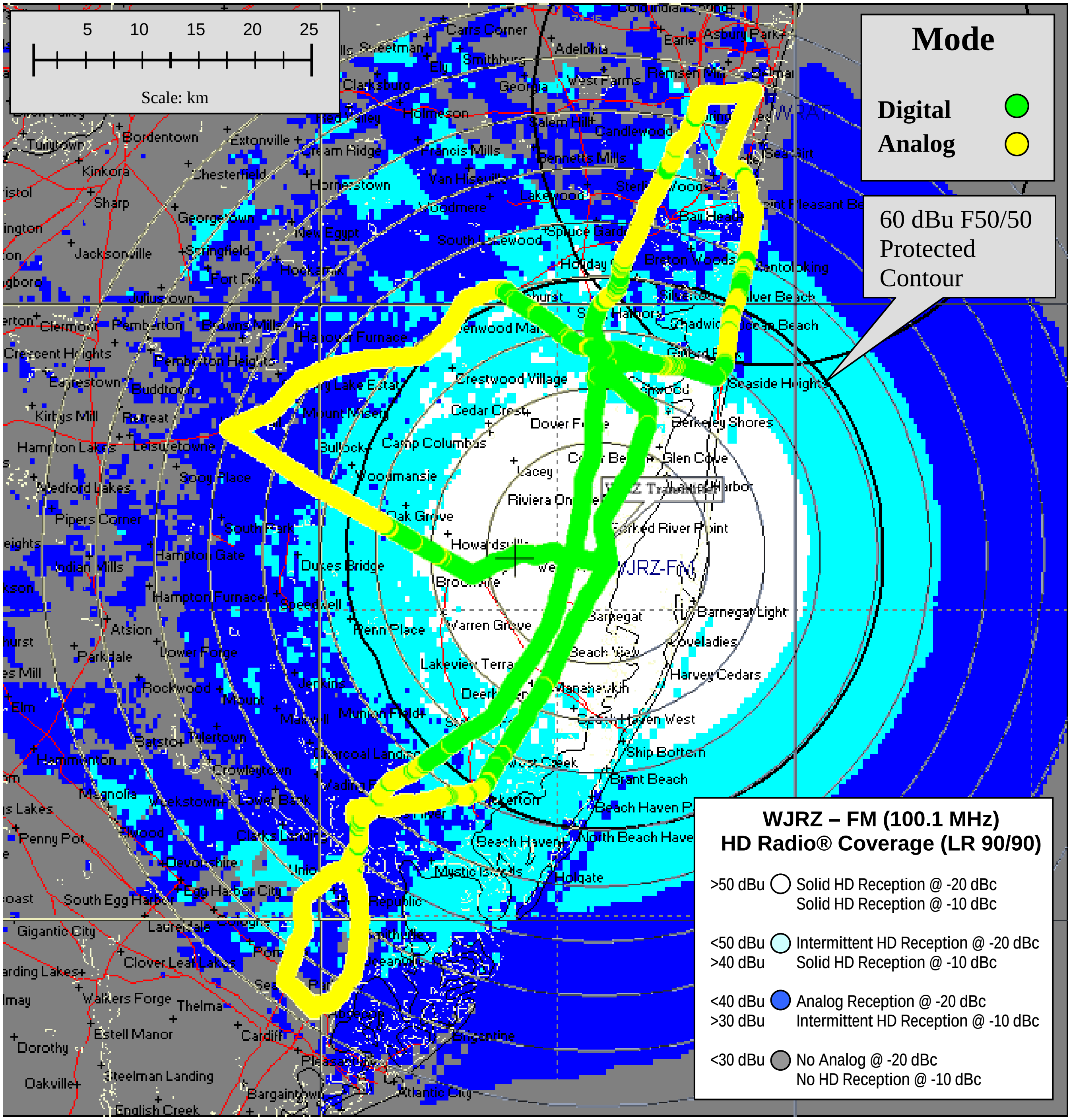


Figure 22 – WJRZ HD Radio™ Coverage @ -20 dBc D/A Power Ratio (All Loops)

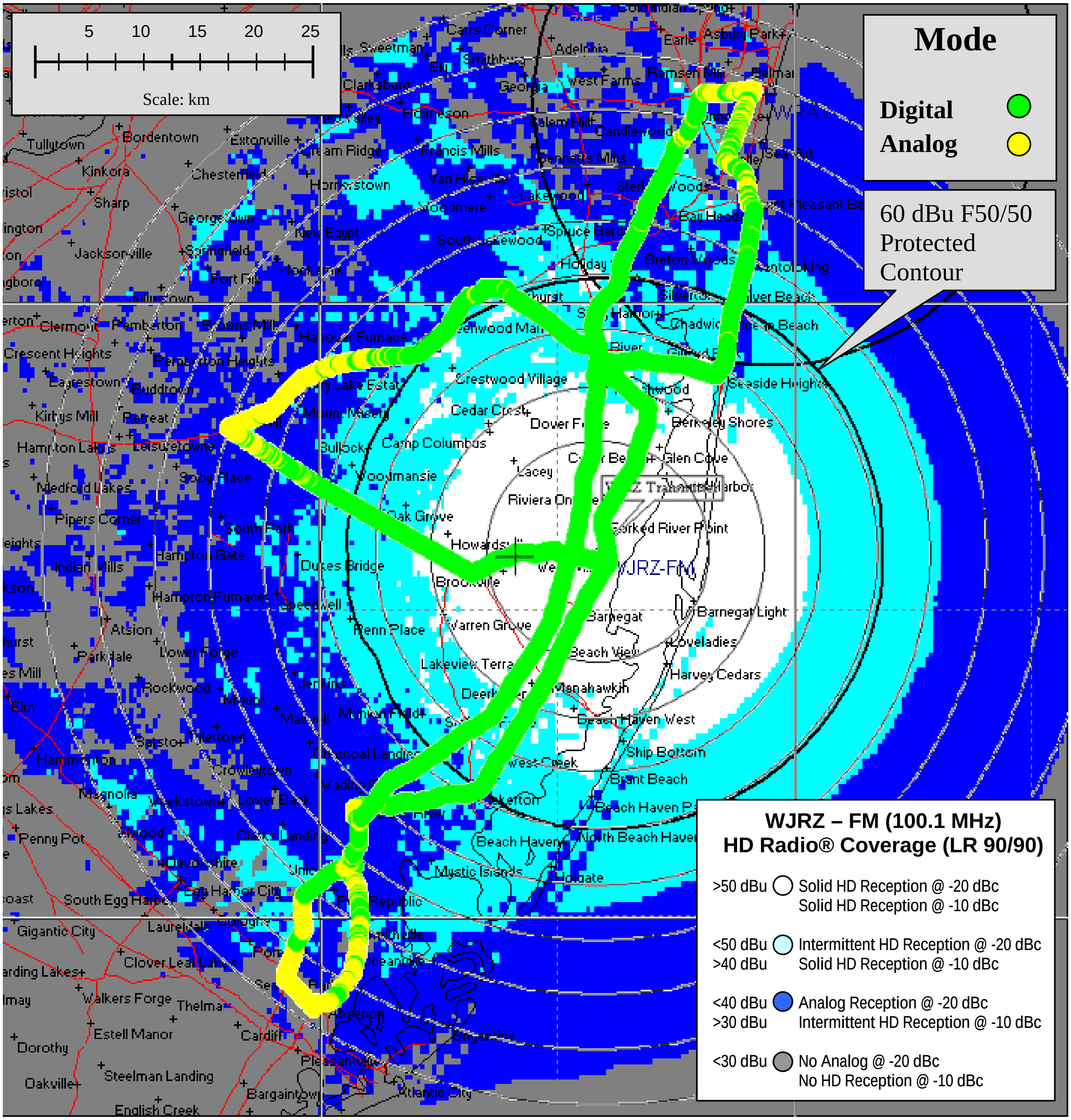


Figure 23 – WJRZ HD Radio™ Coverage @ -10 dBc D/A Power Ratio (All Loops)

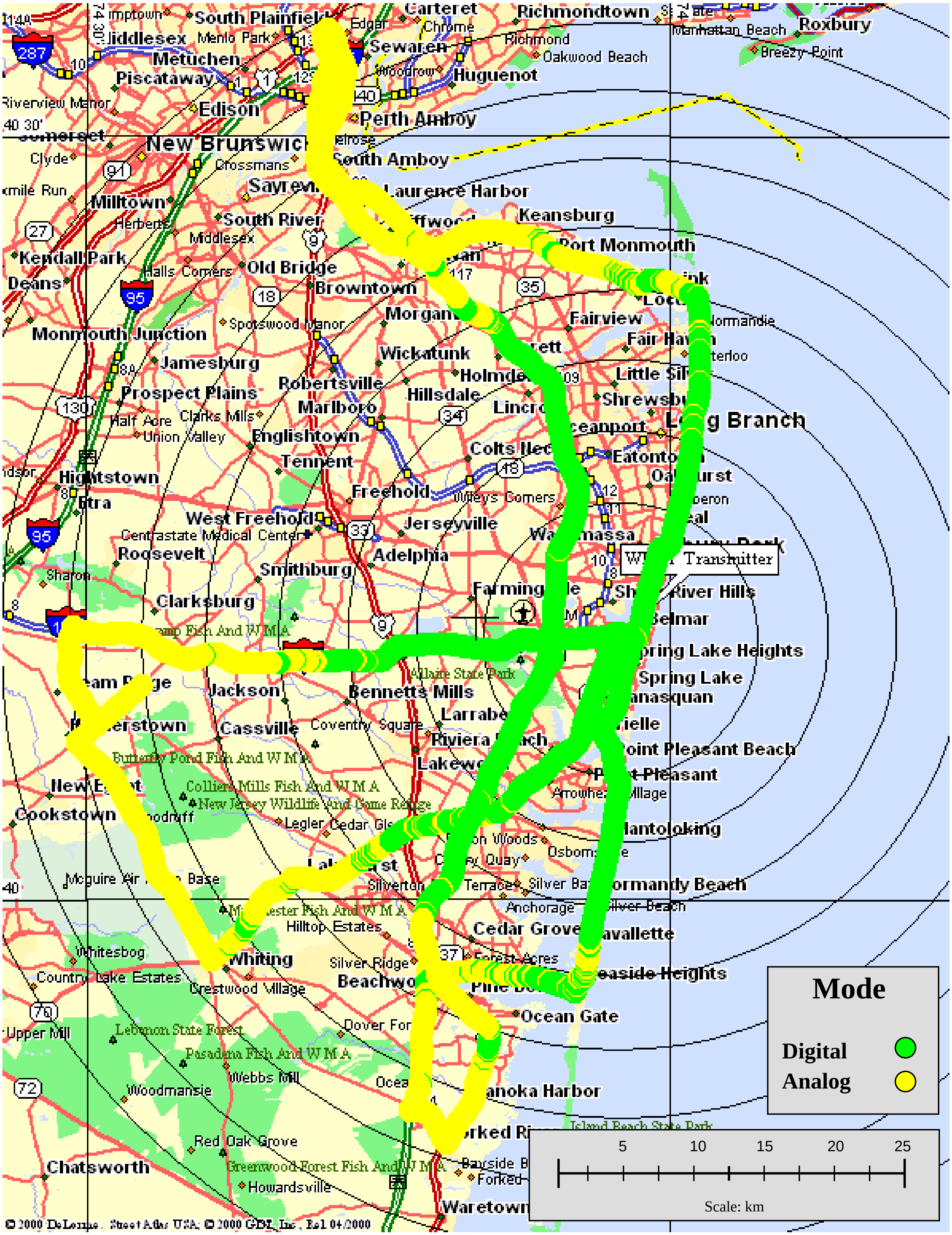


Figure 24 – WRAT HD Radio™ Coverage @ -20 dBc D/A Power Ratio (All Loops)

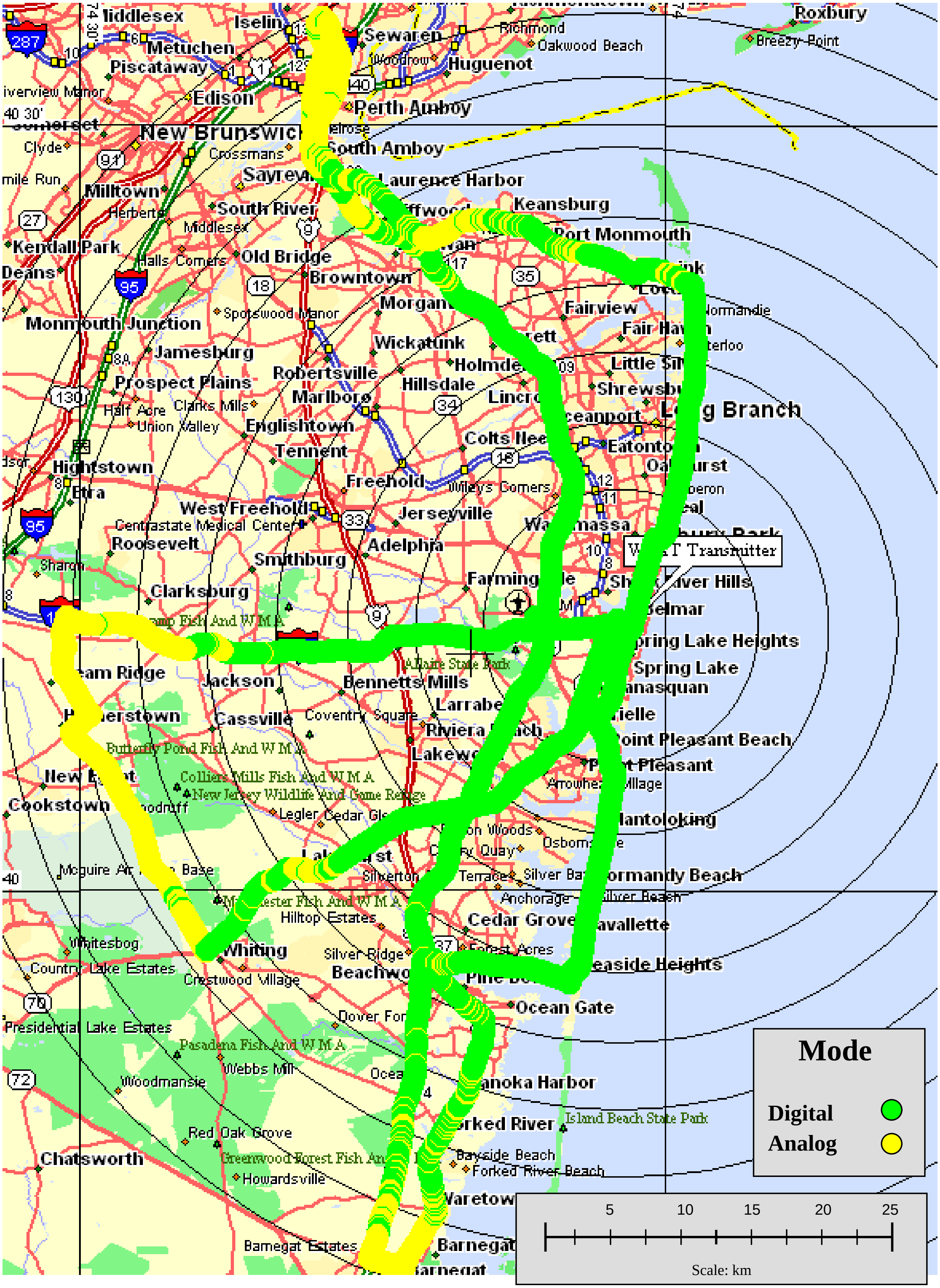


Figure 25 –WRAT HD Radio™ Coverage @ -10 dBc D/A Power Ratio (All Loops)

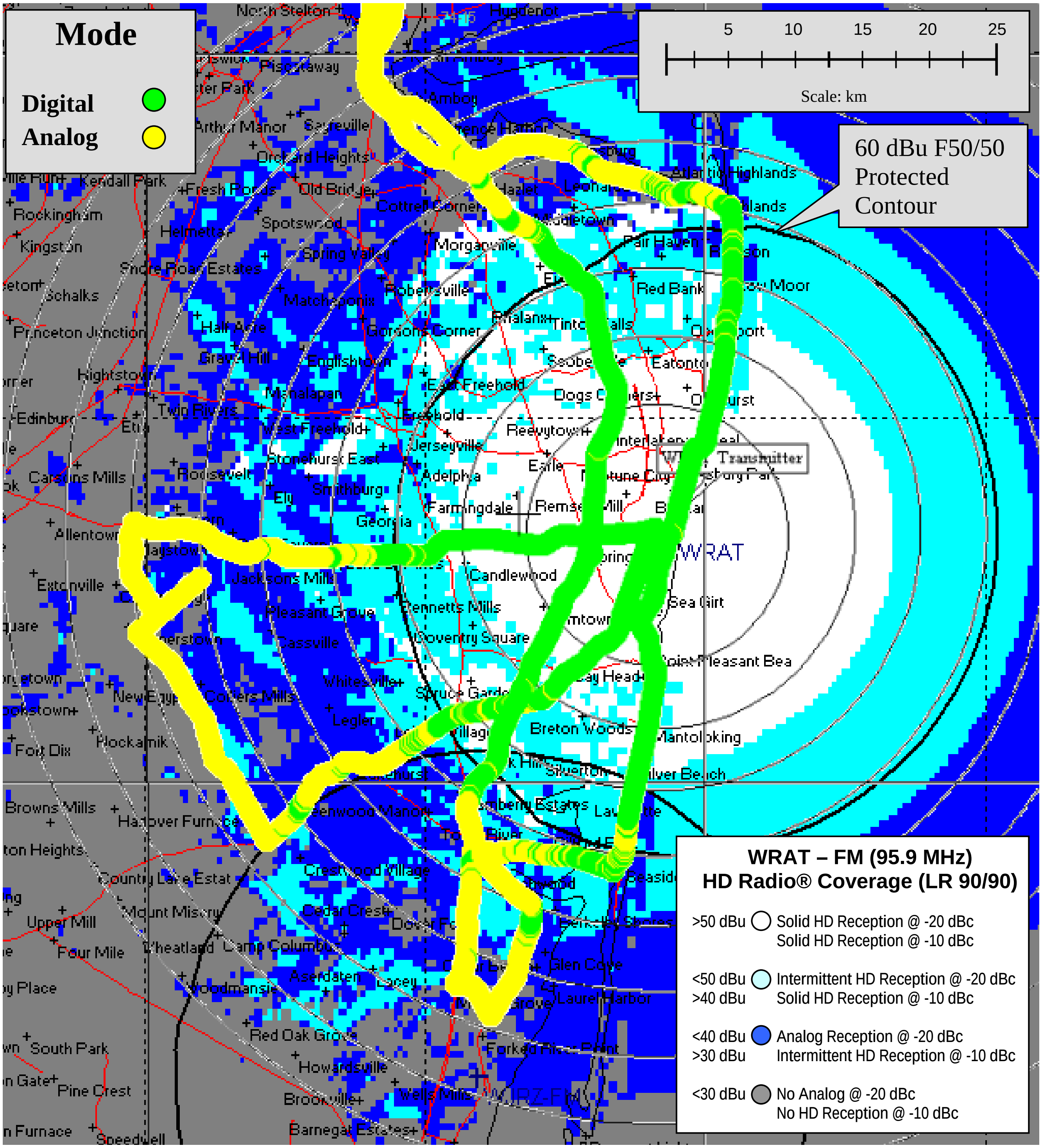


Figure 26 – WRAT HD Radio™ Coverage @ -20 dBc D/A Power Ratio (All Loops)

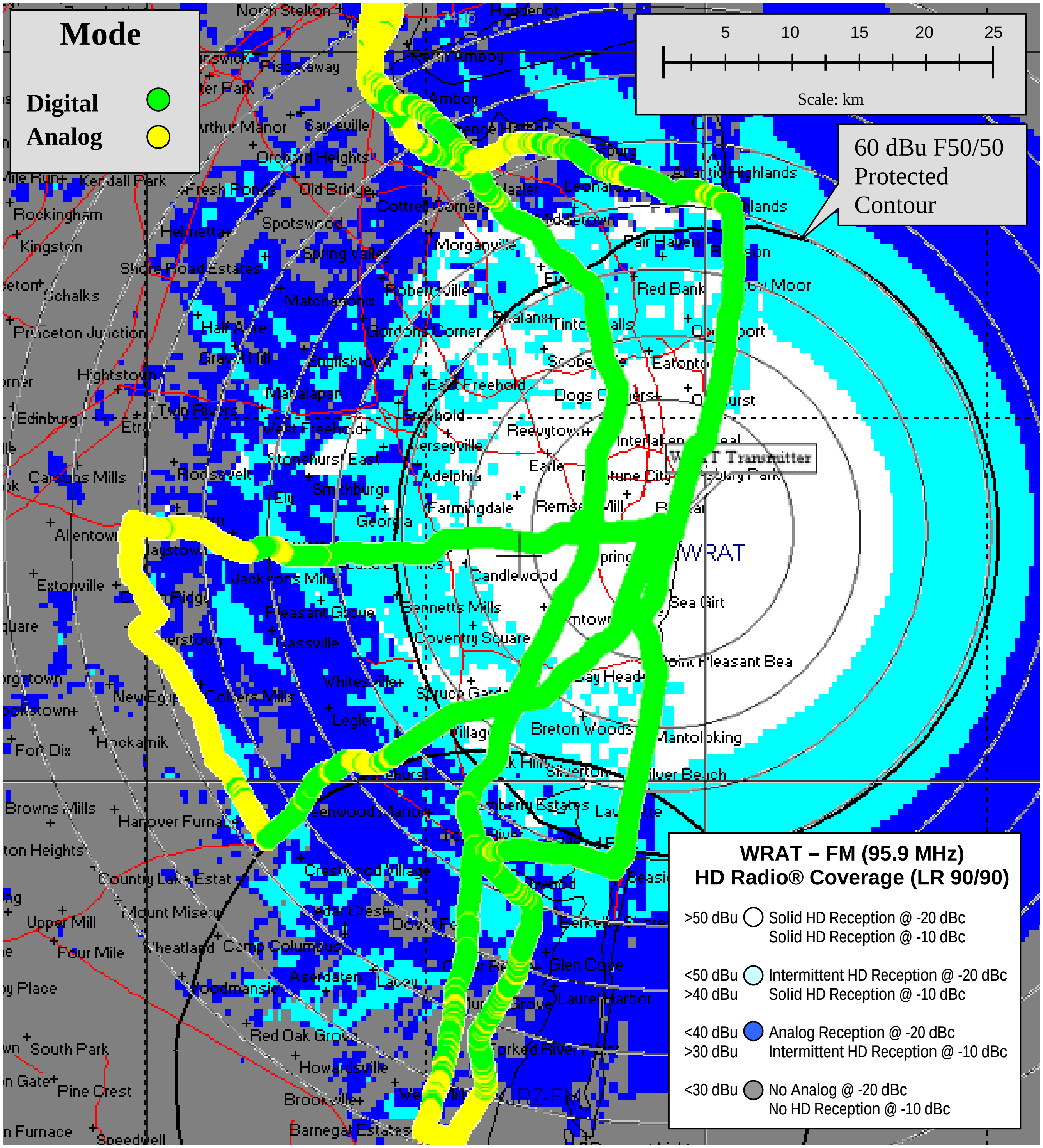


Figure 27 – WRAT HD Radio™ Coverage @ -10 dBc D/A Power Ratio (All Loops)